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ABSTRACT

Some of the major lines of investigation that point to neurophysiological factors in spatial skill are presented. These lines include: the two hemispheres of the brain, recent studies, tachistoscopic studies, morphological differences between the cerebral hemispheres, Geschwind and Levitsky's discovery, cerebral dominance re-examined, sex differences in spatial ability, neuroanatomical basis for sex differences, a model for conceptualizing the effect of differential language lateralization on sex differences in spatial ability, and left-handedness and spatial ability. Further research is recommended. (CK)

NEUROPHYSIOLOGICAL FACTORS IN SPATIAL DEVELOPMENT

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When I was invited to prepare a paper on neurophysiological bases of spatial development, I felt some reluctance, for I have not been formally trained in the neurophysiology of behavior, and my own research has been only on the fringes of this topic -- and then only recently. I expect, then, that my comments will reflect more the perspective of the interested on-looker rather than of someone who has been through it all himself. But if my background as a 'behavioral' developmental psychologist denies me deeper insights into particular neurophysiological issues, perhaps, by way of compensation, it may also lend me a somewhat wider focus on these same issues.

I would like to sketch out in a general way some of what seem to me to be the major lines of investigation that point to neurophysiological factors in spatial skill. We can begin with some simple anatomy.

Man's two brains. The cerebral cortex of the brain is divided into two essentially mirror-image parts, or hemispheres, which are joined together by a massive bundle of interconnecting nerve fibers called the "corpus callosum". The left side of the body is mainly controlled by the right hemisphere, or right side of the cortex, and the right side of the body is mainly controlled by the left hemisphere. The connections, then, are 'contralateral' rather than 'ipselateral'. The two hemispheres 'talk to each other' through their anatomical connection -- the corpus callosum.

This kind of brain design is not unique to man, but what does seem unique to man is that the two hemispheres have very different functions. The left hemisphere is intimately involved in the analysis of speech sounds, while the right hemisphere subserves spatial functions. These different roles historically were inferred from studies of persons who have suffered damage to their brains. Disease involving, for example, the left temporal and parietal areas, is associated with aphasia--impairment in language understanding, disturbances in naming, loss of reading ability. Diseases of the right hemisphere, particularly the posterior area, were associated with disturbances in what can be called visuo-spatial functions.

The British neurologist, Hughlings Jackson was one of the pioneers of the view that the right hemisphere had special functions. In 1874, he argued that the posterior area of the right hemisphere was critical for visual recognition and visual memory. Later he described a patient with a tumor in the temporo-occipital region of the right hemisphere. He diagnosed this tumor and its location on the basis of visual disorientation, failure to recognize persons ("facial agnosia"), and dyspraxia for dressing oneself. Jackson argued that this array of disabilities was as specifically characteristic of disease of the posterior right hemisphere as impairment in expressive speech was of disease of the anterior left hemisphere. Scattered reports followed in the 1880s and 1890s of right hemisphere-related disturbances in spatial orientation as reflected in loss of geographic memory, difficulty in locating objects in space, inability to find one's way around from place to place, and so on. These disturbances were shown by patients suffering from focal cerebral disease and with intact central vision acuity, so that these 'spatial disorders' were 'higher-level', not merely expressions of sensory defects or intellectual impairment.

In 1936 the first really comprehensive study appeared. This was Weisenburg & McBride's monumental study of aphasia which compared right-hemisphere-lesion with left-hemisphere-lesion and control patients on a great variety of psychological tests. The <u>right</u>-hemisphere patients showed significant impairment in <u>nonverbal</u> tasks but with <u>verbal</u> abilities close to normal. In 1953, Critchley published his classic work on the parietal lobes, where he presented evidence that the ability to rotate objects on the level of thought or imagery is an important factor in the constructional-spatial deficits frequently noted after parietal lobe damage. Recently, in <u>Neuropsychologia</u> , Butters & Barton (1970) compared patients with right or left parietal damage on Piaget and Inhelder's three-mountain task. The right parietal-damaged patients did worse.

<u>Recent studies.</u> These studies have the disadvantage that the damage might have occurred many months or years prior to examination, and may have affected not only the specific functional systems but their interaction as well. So it is good that there are also non-neurological techniques for understanding hemispherical asymmetry. One of the most promising is the dichotic listening technique. It usually involves simultaneous presentation of a spoken <u>digit</u> to one ear and a different spoken <u>digit</u> to the other. Several such pairs are delivered in sequence during a trial, and the subject then reports all the numbers he has heard. It has been found that words presented to the right ear are more accurately reported than those presented to the left. Since the left and right ears do not have different basic capacities to detect sound, this right-ear superiority must be related to how the ears are connected to the brain.

Here is where the principle of 'contralteral innervation' referred to earlier is pertinent. Though the auditory system is less crossed, anatomically speaking, than the visual system or the tactual and motor systems, the crossed auditory connections are still stronger than the ipselateral connections. The left hemisphere 'prefers' to listen through the right, contralateral ear, and vice versa (Tunturi, 1946; Rosenzweig, 1951). Since the left hemisphere is specialized for <u>speech</u> perception, it is predictable that <u>speech</u> sounds presented to the right ear would be perceived better, and this is just what many studies show. Vocal <u>non</u>-speech sounds, such as coughing, laughing, and crying, should show a <u>left</u>-ear superiority, which would suggest that they are better processed by the right hemisphere.

A very convincing demonstration of this difference in <u>children</u> was reported by Knox & Kimura in <u>Neuropsychologia</u> in 1970. In one study, involving 80 right-handed children, 5, 6, 7, and 8 years of age, two kinds of sounds were presented: digits, and a variety of environmental sounds. For the digits, the expected right-ear superiority was found at every age.

The pairs of environmental sounds (i.e., non-verbal stimuli) were a dog barking -- dishwashing; phone dialing - clock ticking; water pouring - yawning; coughing - brushing teeth; and several others. For <u>these</u> sounds, the left-ear scores were greater in each age group.

<u>Tachistoscopic studies</u>

Similar differences can be shown in the visual system in tachistoscopic studies. In normal persons, words and letters are reported more accurately from the right visual field (left hemisphere) than from the left visual field, whereas on spatial tasks -- such as the location of a single point in a two-dimensional area -- the right hemisphere (left visual field) is better.

Recently, Durnford, & Kimura reported in <u>Nature</u> (1971) what I think might be the first piece of evidence that the right hemisphere is more critical for depth perception. To the back of a tachistoscope, they attached a box containing a fixed vertical central rod in line with the fixation point. On each side of the central rod was a track on which another vertical rod could be moved. The movable rod is seen with both eyes for only a split second, and the subject must judge whether it is nearer to or farther from the central rod. When the variable rod was presented in the left visual field (so that the information was projected to the right hemisphere), the subjects (college students) were more accurate. Durnford & Kimura also found better right-hemisphere processing of the slant of a line. They projected lines, varying in slope from 15 to 65 deg., one at a time in either visual field. After each projection, the subjects were instructed to identify the projected target from a variety of slanted lines on a sheet of paper. Slope identification was consistently

superior, by a small amount, in the left visual field, or right hemisphere. Here is a very promising area and technique for developmental research.

Morphological differences between the cerebral hemispheres.

If the hemispheres are functionally different, then it would be reasonable to expect them to be physically different as well. But attempts over the last 100 years to find physical asymmetries in the brain itself have met with little success. Allreported differences between the hemispheres in, for example, weight and specific gravity are small and unreliable, and the problem remained to correlate them with the remarkable differences in function.

Geschwind & Levitsky's discovery. In 1968, in Science, Geschwind & Levitsky reported what appear to be convincing anatomical differences. They studied 100 adult brains, obtained at postmortum, and free of significant pathology, They divided the hemispheres and then exposed the upper surface of the temporal lobe on each side by cutting into the plane of the Sylvian fissures. (They thus exposed the top of the temporal lobes to full view.) Here they found that a particular portion of the temporal lobe -- the planum temporale -- was about 9 millimeters or a third larger on the left in about 65 percent of the brains, equal in 24 percent, and larger on the right in about 11 percent.

This enlarged part of the brain is in an area which makes up part of the temporal speech cortex, an area intimately involved in the higher analysis of speech sounds.

In a later paper Geschwind (1970, p. 944) mentions confirmation of these results by the Japanese neurologist, Juhn Wada (1969). And I have recently seen a report that Wada has found the same planum asymmetry in the brains of 5-month-old fetuses and newborns (i.e., still-borns).

A second anatomical difference relevant to the question at issue is found in the parietal occipital area. It has been known for many years that there is an asymmetry of the occipital horns of the lateral ventricles, with the left occipital horn usually larger (Penfield, 1925; cited in McCrae et al., 1968). If the occipital horn is larger, this means that the corresponding part of the cortex will be smaller. In 1968, in Neurology, McCrae, Branch, & Milner reported finding in neurosurgical patients that a longer left occipital horn correlated moderately well with right-handedness. There were too few left-handers for analysis, but left-handed patients tended to have longer right horns, or larger left cortexes.

So from Geschwind & Levitsky's work, we know that a part of the temporal lobe subserving speech functions is larger in the left hemisphere, and from McCrae, Branch, & Milner's work, we have at least indirect evidence that the parieto-occipital lobe, important for spatial-visual perception, is larger on

the right in right-handers. The results thus seem to agree with the neurological case studies and the dichotic listening and tachistoscopic studies, and provide anatomical bases for the observed functional differences.

Some might object that these anatomical differences are bases on pathological case material, and are either not correlated with behavioral aspects of cerebral dominance (Geschwind & Levitsky), or include too few left-handed subjects to permit really convincing statistical analysis (McCrae et al.). This situation is improved somewhat be research recently reported in Behavioral Biology by the Israeli neurologist, Amiram Carmon. Carmon found hemispheric differences in blood supply correlated with handedness in 85 healthy 15- to 23-year-olds. It has been known for a long time that the blood supply to the two hemispheres of the human brain is markedly asymmetric. The right cerebral hemisphere is supplied from a vascular trunk which it shares with the right upper extremity, while the left hemisphere is supplied directly from the aortic arch, This inequality of blood supply was advanced in the early 1900's as an explanation of sidedness, the contention being that because of the asymmetrical arterial system, the blood supply of the cerebral hemispheres was unequal, and that handedness would depend on the hemisphere receiving the greater supply. What Carmon did was to inject hippuran labled with radioactive iodine into the vein of the arm and then release it abruptly. Two scintilators placed over the two hemispheres recorded gamma irradiation, and two curves were obtained, one for each hemisphere. The peak and area of the curves designate blood volume in each hemisphere. The behavioral measures of dominance were hand preference as measured by a questionnaire and dichotic listening to verbal stimuli (Kimura, 1967). The results indicated that right hand or right ear preferences were associated with larger blood volume in the right hemisphere. Left handedness and left ear preference were associated, but somewhat less strongly, with larger blood volume in the left hemisphere. When the two measures of preference were combined, the associations were stronger. Thus the hemisphere dominant for speech was less well equipped in blood supply than the 'minor', spatial hemisphere -- precisely the opposite of what might be expected.

I might mention, too, findings of Paoluzzi & Bravaccio of differential prevalence of bioelectrical cerebral pathology in the two hemispheres. Examination of a total of 4,032 EEG records of patients with diagnosed exclusive or prevalent localized pathology in a single hemisphere disclosed more frequent pathology in the left hemisphere by a ratio of 7:3. Paoluzzi & Bravaccio (1967) conclude that the left hemisphere is more vulnerable -- a conclusion possibly consistent with Carmon's findings.

Cerebral dominance re-examined

How to account for the finding that the speech hemisphere - what is

traditionally called the 'dominant' hemisphere - is less well-supplied with blood than the spatial, non-dominant hemisphere? Let me suggest, in answer, that to call one hemisphere 'dominant' and one 'minor' is to make a value judgment more than a scientific judgment. Human beings have been around in something like their present form for somewhere between 3 and 6 million years. For how many have they been verbal, cognizing, symbol-using, articulate creatures? I should think for only a small fraction of this time. Speech, evolutionarily speaking, is a relatively recent development. For a much longer time, Man has been a tool-using, hunting, creature whose indulgences in the fine art of conversation were few and far between. It makes sense to me that Man, given the sorts of environmental challenges posed to him for most of his existence, should have developed a good spatial sense.

Whether this sort of 'explanation' makes much sense or not, Carmon's results -- if we could extrapolate back several years in a child's life -- seem to be compatible with the recent developments in the psychology of infancy. It has been said that developmental psychologists are 'rediscovering' the infant and rescuing him from the doldrums of cognitive inactivity. Now we have reason to believe that infancy is a period of substantial intellectual growth. What is the nature of this very early development? It is what we could well call the development of spatial knowledge -- knowledge of the layout of the world and of one's body in the world. Thus the infant comes to know, or learn, how long his arms are, what can be reached for and grasped, that something that disappears from sight does not cease to exist.

Other indications of very early spatial development are the appearance, within the first few months of life, of head and eye orientation to a sound source in the peripheral visual field, which Piaget (1953) has interpreted as evidence for early coordination of auditory and visual space. Even at birth some psychomotor coordination is apparently present. In babies only a few minutes after delivery, Wertheimer (1961) observed directionally appropriate eye movements to a sound source.

Recently, Aronson & Rosenbloon reported in Science in 1971 that infants as young as 30 days of age become visibly distressed on observing their mothers speaking to them while the mother's voice is displaced in space. The spatial dislocation, these investigators suggest, apparently violates the infant's perceptual world in which speaker and voice share the same spatial position. "The infant presumably learns to expect that voice and speaker are a spatial unit, but the learning would require the prior existence of a perceptual system that has access to and reliably coordinates information from separate modes" (p. 1163).

We know too that infants very quickly come to recognize the parent's face

and to distinguish that face from all other faces. Facial recognition is a perceptual skill subserved by the right hemisphere. Adults with right-hemisphere lesions often show impaired ability to recognize and remember faces (De Renze & Spinnler, 1966).

Taking Carmon's findings that the right hemisphere is better supplied with oxygen than is the left hemisphere, the electroencephalographic data indicating more common left-hemisphere lesion, a variety of findings indicating strong dependence of facial recognition ability on intactness of the right hemisphere, we can hypothesize that the rapid and strong spatial learning of the very young infant indicates strong right-hemisphere functioning. In other words, the human infant is neuroanatomically disposed to effective spatial learning.

Perhaps, if we are to retain the expression 'major' hemisphere, we might speak of the right hemisphere as the 'major' hemisphere for infancy and very early childhood -- the period before speech comes in strongly.

I would like to mention one more piece of what I think may be evidence for right hemisphere preference in infancy. Recently, Turkewitz, Gordon, & Birch (1965) observed the head positions of 100 normal infants ranging in age from several minutes to slightly over 100 hours. On more than 3,000 observations during which the infants were observed while lying on their backs, their heads were turned to the right of body midline during 88.0 percent of them. Why does the infant prefer the head-to-right posture? This posture would cover the <u>right</u> ear. Is this therefore an indication of preference for the <u>left</u> ear? Since in the case of audition, the contralateral connections are better than the ipselateral connections, does this means the infants therefore are getting better 'input' to the right cerebral hemisphere? Recalling the dichotic listening results, could this be evidence that the <u>right</u> hemisphere is, even in earliest infancy, better for detecting <u>environmental</u> auditory stimuli? It would extremely interesting to test infants on Aronson and Rosenbloom's (1971) test of visuo-spatial coordination and compare infants according to <u>strength</u> of head-to-right preference during the first 30 days of life. Would infants with strong <u>head</u>-right preference show more or earlier evidence of detecting the mismatch between mother's face and mother's voice? Would they be more alert to environmental sounds?

<u>Sex differences in spatial ability</u>

The discovery of anatomical differences associated with functional differences between the hemispheres in turn suggests a new way of looking at sex differences in spatial ability. These differences are well-substantiated but not well understood. That is, no one really denies that boys are better in spatial tasks, but no one is quite clear how boys' superiority should be explained.

Neuroanatomical basis for sex differences. Could there be any neuroanatomical basis? I already have referred to the discovery that the speech area of the left hemisphere is larger than the corresponding area in the right hemisphere. Wada (1972) has looked at this anatomical difference in terms of sex and found that the female brain tends to have a larger speech area in the right hemisphere. Another way to put this is to say that in females, language is more nearly bilaterally represented, so that females are less lateralized for language. Males, contrarily, are more lateralized for language, with the left hemisphere more nearly exclusively subserving speech functions, the right hemisphere, spatial functions. This difference perhaps is a clue to understanding sex differences in the effects of brain injury. Lansdell (1961) studied the ability to understand proverbs after removal of the left temporal lobe. Males showed lowered ability, but females did not.

Eisenson (1962) compared patients with right cerebral damage with non-damaged control patients on tasks that required language comprehension at a relatively high level -- completion of open-ended sentences and word definitions. Female patients showed less linguistic and intellectual impairment than did men of comparable age.

Therefore, linguistic impairment following left-brain injury seems to be less severe in females than in males. Wada suggests that this is because females have a larger residual language area in the right hemisphere.

Sex differences also appear on dichotic listening tasks. In the Knox and Kimura study on perception of environmental sounds, I mentioned earlier, the combined left-ear scores plus right-ear scores were greater for boys than for girls at all 4 ages -- five, six seven, and eight years -- with the over-all scores significantly greater for boys.

Sex differences also appeared in a second study, with two-and-a-half to five-year olds. This study was not a dichotic study: animal sounds were simply played through a tape recorder, and the child was asked to name or describe the animal he had heard after each sound was played. The boys did significantly better than the girls.

Knox & Kimura are reluctant to credit the boys' superior performance to superior labelling of what was perceived, since all the evidence suggests instead that girls in this age range surpass boys in the use of expressive language (McCarthy, 1954). Nor do they think there is any basis for postulating differential experience of boys and girls with these environmental sounds, for most were equally common to the experience of both sexes -- or seemed to be. The authors instead favor an explanation in terms of a sex difference in innate psychological capacities or in differential maturation of functions. They conclude on the same note as Wada does: "... since both

spatial abilities and non-verbal auditory perception seem to be subserved predominantly by the right hemisphere, and since males perform significantly better than females on tasks involving these functions, it seems possible that the right hemisphere does not function identically in males and females. Thus, male superiority on these right-hemisphere dependent tasks may be related to greater right-hemisphere lateralization of these functions in males than in females" (knox & Kimura, p. 235).

<u>A model for conceptualizing the effect of differential language lateralization on sex differences in spatial ability.</u>

What we still lack is a <u>model</u> for conceptualizing the precise effect of such inferred different degrees of <u>language</u> lateralization between males and females on the observed differences between the sexes in <u>spatial</u> ability. One obvious model would be that females have better verbal skill, but worse spatial skill than males, simply because those parts of their brains subserving verbal skills and spatial skills are, respectively, larger and smaller than those same parts in the brains of males. This model, at least crudely, is consistent with the neuroanatomical findings.

A somewhat subtler model, however, may be possible. In a recent paper in <u>Nature</u> (1969), Jerre Levy has suggested that there are two <u>modes</u> of information-processing, each mode specific to a single hemisphere. The mode specific to the left hemisphere is 'analytic', that specific to the right hemisphere is 'synthetic' or Gestalt-like. Levy further suggests that these two modes are antagonistic, and that the evolutionary reason for lateral specialization is to produce a division of labor with respect to these antagonistic functions.

So for females, with speech representation more nearly bilaterally represented, the two antagonistic functions occur <u>together</u> in the right hemisphere. Is it possible that for this reason, spatial-visual tasks (right-hemisphere tasks) would be performed less effectively by females? In females there would be this antagonism or competition within the hemisphere between the two modes -- speech and spatial, analytic and synthetic -- in the analysis of spatial problems. It is not, then, so much that females have absolutely more speech representation (or less spatial-visual representation) than that there is this mixing-up or competition between the two modes of thinking.

<u>Left-handedness and spatial ability</u>

All the foregoing discussion suggests still further extension -- beyond male-female differences to differences between handedness groups. (And now approximately 4 to 8 percent of you should begin to stir with special interest as is only proper for members of a minority group which has for too long suffered under the hand of a powerful and uncaring majority. I refer, of course, to those of us who are [illegible]-handed, wacky-handed, gammy, keggy, scrammy,

skiffly, skivvery, watty, coochy, schoochy, scroochy, squiffy, bawky, cowey, cowley, hawky, garpawed, kay-pawed, cow-pawed, and south-pawed -- us <u>left-handers</u>. These are just some of the slang terms heaped on the lefty by the British -- all collected by Samuel Orton and reported by Michael Barsley, an estimable philo-left-hander, in his book <u>Left-handed man in a right-handed world</u> (1970, pp 157-158).

I refer you to Barsley's book for discussion of the etymology of these terms. Suffice it to say that nearly all are mean-spirited.

We also might quote Subirana (1969), who might be speaking for all the scientists who have sought to understand the relation between handedness and brainedness and who proposes the novel, if jocular, genetic theory that ". . . left handers seem to have been created on purpose to upset all the different conceptions which have prevailed during the last century in connection with the pathology and physiology of the two hemispheres" (p.248).

Left-handed children and adults are interesting and perplexing because they seem to have poorer spatial ability than right-handers.

Is there anything about the brains of left-handers which might account for their often noted poor spatial sense? The answer seems to be that the same kind of evidence already cited of differences in lateralization between males and females applies also in the case of left-handers. For example, in left-handers, like females, linguistic ability is more likely to withstand left-hemisphere damage (Hecaen & Ajuriaguerra, 1964). And on hand usage tests, though they are imperfect indexes of cerebral lateralization, left-handers are less lateralized than are right-handers (Benton, 1962). The indications, therefore, are that in left-handers, like females, language functions are more nearly bilaterally represented, i.e., with more language capacity in the right hemisphere. Left-handers' <u>spatial</u> ability therefore might be impaired because of the resulting antagonism or competition within the 'spatial' hemisphere between the spatial and verbal modes.

<u>Conclusions</u>

These are just some of the kinds of researches which are uncovering neurophysiological bases for spatial perception. Obviously, much more could be said and needs to be said about the relation between neurophysiological development and psychological development. Here, we really are just beginning.

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